

**IN THE UNITED STATES DISTRICT COURT  
FOR THE WESTERN DISTRICT OF TEXAS  
WACO DIVISION**

GESTURE TECHNOLOGY PARTNERS,  
LLC,

Plaintiff,

v.

APPLE INC.

Defendant.

Case No. 6:21-cv-00121-ADA

**JURY TRIAL DEMANDED**

GESTURE TECHNOLOGY PARTNERS,  
LLC,

Plaintiff,

v.

LENOVO GROUP LTD., LENOVO  
(UNITED STATES) INC., and MOTOROLA  
MOBILITY LLC,

Defendants.

Civil Case No. 6:21-cv-00122-ADA

**JURY TRIAL DEMANDED**

**DECLARATION OF CHARLES D. CREUSERE, PH.D. IN SUPPORT OF  
DEFENDANTS' RESPONSIVE CLAIM CONSTRUCTION BRIEF**

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I, Charles D. Creusere, Ph.D., hereby state and declare:

## **I. INTRODUCTION**

1. I am over the age of 18 and am competent to make this declaration. I have personal knowledge, or have developed knowledge, of these technologies based upon my education, training, and/or experience, of the matters set forth herein.

2. I have been retained by counsel for Defendants Apple Inc., Lenovo (United States) Inc., and Motorola Mobility LLC (collectively, “Defendants”), in the above captioned matters to offer opinions as to the scope and meaning that would have been given to certain disputed terms and phrases in U.S. Patent No. 7,933,431 (the “’431 Patent”), U.S. Patent No. 8,194,924 (the “’924 Patent”), U.S. Patent No. 8,553,079 (the “’079 Patent”), and U.S. Patent No. 8,878,949 (the “’949 Patent”) (collectively, the “asserted patents”) by one of ordinary skill in the art at the time of the inventions.

3. I have been asked by counsel to provide my opinions on the construction of the following disputed claim terms:

<b>Disputed Claim Term</b>	<b>Asserted Claims</b>
“a computer means within said housing for analyzing said image to determine information concerning a position or movement of said object”	’431 patent cl. 7
“means for controlling a function of said apparatus using said information”	’431 patent cl. 7
“the detected gesture is identified by the processing unit apart from a plurality of gestures”	’949 patent cl. 13
“forward facing [portion / light source]”	’949 patent cls. 1, 5, 8, 13, 16

4. For purposes of this declaration, I have not been asked to opine on the meaning of any other disputed terms not identified above.

5. In rendering my opinions, I have reviewed the intrinsic evidence, including the text of the asserted patents, their file histories, extrinsic evidence, and the declaration of Plaintiff Gesture Technology Partners, LLC's ("Gesture") expert, Dr. Benedict Occhiogrosso. My opinions are based on my years of education, training, research, knowledge, and personal and professional experience in the relevant art.

6. I reserve the right to supplement and/or amend my opinions in this declaration based on future opinions taken by the parties, their experts, additional documents, testimony, or other information provided by the parties or their witnesses, any orders from the Court, or as otherwise necessary.

## **II. QUALIFICATIONS AND EXPERIENCE**

### **A. Educational Background**

7. I received a Bachelor of Science degree in Electrical and Computer Engineering from the University of California at Davis in 1985. I received a Master's of Science degree in Electrical and Computer Engineering from the University of California at Santa Barbara in 1990, and I received my Ph.D. in Electrical and Computer Engineering, also from the University of California at Santa Barbara, in 1993.

### **B. Professional Experience**

8. I am currently a Full Professor in the Klipsch School of Electrical & Computer Engineering at New Mexico State University, and I hold the Frank Carden Endowed Chair in Telemetering and Telecommunications. I was an Assistant Professor at New Mexico State from January 2000 until I became an Associate Professor in 2004. I have been a Full Professor since August 2010. My research and teaching at New Mexico State have focused on digital signal and image processing.



9. I have extensive experience in the technical areas of the asserted patents, including more than 30 years of experience with image processing theory and practice.

10. After receiving my B.S. from U.C. Davis in 1985, I went to work for the Naval Weapons Center, China Lake as a civilian Department of Defense (DoD) employee. From 1985 until the program was handed off to a contractor in 1989, I was the lead designer for the guidance electronics of the Laser Guided Training Round. My work on this project included analog and digital circuit design, embedded software design, and front-end systems integration and testing. In 1989, I was awarded a fellowship from the DoD to pursue graduate degrees at the University of California, Santa Barbara. After returning to China Lake with my Ph.D. in 1993, I continued to pursue practical engineering projects along with my more theoretical endeavors. The most encompassing of these projects involved developing efficient video compression and decompression algorithms for use with wireless communication channels. These algorithms were designed for real-time streaming in a manner that maximized bandwidth efficiency while ensuring that the quality of the most important information in the data stream was preserved. During my Masters program at UCSB, I pursued a dual communications/digital signal processing coursework specialization and, as a result, took the following relevant graduate classes: ECE242 (Digital Coding of Analog Signals), ECE278 (Image Processing), ECE258 Digital Signal Processing, ECE148 (Real-Time Digital Signal Processing), ECE277B (Pattern Recognition), ECE243 (Digital Communication), ECE594C (Error Control Codes), and ECE205A (Information Theory). ECE278 (Image Processing) and ECE277B (Pattern Recognition) are particularly pertinent here given that the asserted patents focus on recognizing gestures in captured imagery. In addition to the above, as part of my minor area of specialization in computer engineering, I took classes in linear and nonlinear programming, optimization theory, neural networks, and computational linear

algebra. My Ph.D. research was focused on the compression of images and audio using multirate filter banks and wavelets, and I continued to do research in this area for the six years I spent working at the Naval Air Warfare Center in China Lake, CA after completing my dissertation.

11. I have published numerous peer reviewed journal articles and conference papers including 17 journal and 86 conference papers. Some of the papers I wrote which are relevant to the asserted patents and related art include:

- C.D. Creusere and A. Van Nevel, "ATR-directed image and video compression," *Journal of Aircraft*, Vol. 36, No. 4, pp. 626-31, July-August 1999.
- V. Thilak, D. Voelz, and C.D. Creusere, "Polarization-based index of refraction and reflection angle estimation for remote sensing applications," *Applied Optics*, Vol. 46, Bo. 30, pp. 7427-7536, Oct. 2007.
- V. Thilak, C.D. Creusere, and D. Voelz, "Passive Polarimetric Imagery-Based Material Classification Robust to Illumination Source Position and Viewpoint," *Image Processing, IEEE Transactions*, vol.20, no.1, pp.288-292, Jan. 2011.
- L. Zhou and C.D. Creusere, "Spatial object detection in JPEG bitstreams," *Proceedings European Conference on Signal Processing*, pp. 949-52, Sept. 2004, Vienna, Austria.
- V. Thilak and C.D. Creusere, "Tracking of extended size targets in H.264 compressed video using the probabilistic data association filter," *Proceedings European Conference on Signal Processing*, pp. 281-4, September 2004, Vienna, Austria.

12. Since joining the faculty of New Mexico State University in 2000, I have taught numerous classes at both the graduate and undergraduate levels. These include EE497 (Digital Communications), EE585 (Telemetry Systems), EE573 (Signal Compression), EE596 (Image Processing), and EE586 (Information Theory). In the course of teaching these various classes, I cover much of the signal processing that facilitates modern digital communication systems, including video transmission and processing.

13. A listing of the cases (including trials before the Patent Trial and Appeal Board) in which I have testified within the last four years is found in my CV, which is attached as **Exhibit A**. Also included in **Exhibit A** is a complete list of my publications and patents.

**C. Other Relevant Qualifications**

14. In addition to the experience and publications listed above, I have also received the following awards and distinctions that are relevant to the subject matter of this declaration. I am currently a Senior Area Editor for IEEE Transactions on Image Processing and have previously served as an Associate Editor for IEEE Transactions on Image Processing from 2010 through 2014. I have also served in this capacity from 2002 through 2005. From 2008-2013, I served as an Associate Editor for IEEE Transactions on Multimedia.

15. In 2004, I served as the co-general chair for the IEEE Digital Signal Processing Workshop in Taos, New Mexico. In 2012 and 2014, I served as the co-technical chair for the Southwest Symposium on Image Analysis and Interpretation held in Santa Fe, New Mexico and San Diego, CA, respectively. In addition, I also served as the technical chair for the 2015 and 2021 International Telemetering Conferences, both held in Las Vegas, Nevada. I have been a member of the technical program committee for the IEEE Data Compression Conference since 2007 and I continue to serve in that capacity at the present time. I am also a member of the technical program committees for other conferences that include many papers in the area of image processing including the IEEE International Conference on Image Processing (ICIP), the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), and the European Signal Processing Conference (EUSIPCO).

**D. Compensation and Previous Expert Opinions**

16. I am being compensated at my usual rate of \$350 per hour for each hour of service that I provide in connection with this case, including time I spend consulting, writing this report, giving deposition testimony and testifying. My compensation does not depend in any way on the content of my testimony and is not affected by the outcome of the case. If called to testify as to the contents of this report, I can and would testify truthfully and competently.

### III. LEGAL PRINCIPLES

17. I have been informed by counsel for Defendants that the following principles of law are applicable to claim construction, and I have applied these principles in my analysis.

18. The claims of a patent define the limits of the patentees' exclusive rights. In order to determine the scope of the claimed invention, courts typically construe claim terms when the meanings are disputed by the parties. Claim terms should generally be given their ordinary and customary meaning as understood by a person of ordinary skill in the art at the time of the invention.

19. Claims must be construed in light of, and consistent with, the patent's intrinsic evidence. Intrinsic evidence includes the claims themselves, the written disclosure in the patent's specification, and the patent's file history.

20. In the specification, a patentee may also define his own terms, give a claim term a different meaning than it would otherwise possess, or disclaim or disavow claim scope. A court may generally presume, however, that a claim term possesses its ordinary meaning.

21. The prosecution history can also inform the meaning of the claim language by demonstrating how the patentee and the PTO understood the invention and whether the patentee limited the invention in the course of prosecution, making the claim scope narrower than it would otherwise be.

22. Courts can also consider extrinsic evidence when construing claims. Extrinsic evidence is any evidence that is extrinsic to the patent itself and its prosecution history. Examples of extrinsic evidence include technical dictionaries, treatises, and expert testimony. I understand that extrinsic evidence is less significant than the intrinsic record in determining the meaning of claim language.

23. A claim is indefinite if its language, when read in light of the specification and prosecution history, fails to inform persons having ordinary skill in the art about the scope of the claimed invention with reasonable certainty. I have been informed by counsel that reasonable certainty does not require absolute precision.

24. I am informed that if the word “means” is used in a claim limitation, there is a rebuttable presumption that § 112, ¶ 6 is applicable. This presumption may be overcome and § 112, will not apply if the claim itself recites sufficient structure for performing the claimed function.

25. On the other hand, when a claim term lacks the word “means,” there is a rebuttable presumption that § 112, ¶ 6 is not applicable. This presumption can be overcome and § 112, ¶ 6 will apply if it can be demonstrated that the claim term fails to recite sufficiently definite structure or else recites function without reciting sufficient structure for performing that function. The claim language itself may provide sufficient structure if it is not necessary to resort to other portions of the specification or extrinsic evidence for an adequate understanding of the structure.

26. I am informed by counsel that if § 112, ¶ 6 is applicable for a particular claim limitation, then the specification must clearly link or associate structure to the function recited in the claim. Even if the specification discloses corresponding structure, the disclosure must be of adequate corresponding structure to achieve the claimed function. I am informed by counsel that if such structure is disclosed, then the limitation is limited to that structure and its equivalents. On the other hand, I am informed by counsel that if no adequate corresponding structure is disclosed, then the claim limitation is indefinite. I have been informed by counsel that the testimony of one of ordinary skill in the art cannot supplant the total absence of structure from the specification. I have been informed that it is irrelevant to the indefiniteness inquiry whether a person of ordinary skill in the art would find it obvious to derive an otherwise missing structure.

27. I am informed by counsel that in at least certain situations, material incorporated by reference cannot be relied upon for providing structure for a claim limitation governed under § 112, ¶ 6. I have nevertheless considered the material incorporated by reference in the asserted patents in forming my opinions.

28. I am informed by counsel that for a computer-implemented means-plus-function limitation that cannot be performed by a general purpose computer without additional programming, the disclosed structure under § 112, ¶ 6 is not just a general purpose computer, but also the algorithm implemented by the computer. Therefore, for a computer-implemented means-plus-function limitation, the specification must disclose more than a general purpose processor—it must disclose an algorithm for performing the entire claimed function. I am informed that if no algorithm is disclosed for a computer-implemented means-plus-function limitation, then the claim is indefinite.

29. I have been informed by counsel that mere reference to a general purpose computer being appropriately programmed without providing an explanation of the appropriate programming, or simply reciting “software” without providing detail about the means to accomplish a specific software function, would not be an adequate disclosure of the corresponding structure to satisfy the requirement of definiteness under U.S. patent law. Further, merely referencing a specialized computer (e.g., a “bank computer”), some undefined component of a computer system (e.g., an “access control manager”), “logic,” “code,” or elements that are essentially a black box designed to perform the recited function, will not be sufficient because there must be some explanation of how the computer or the computer component performs the claimed function.

30. I am informed by counsel that a patentee may express the algorithm in any understandable terms, including as a mathematical formula, in prose, as a flowchart, or in any other manner that provides sufficient structure.

31. I am informed by counsel that if multiple functions are claimed for the same element, the patentee must disclose adequate corresponding structure to perform all of the claimed functions. For a computer-implemented means-plus-function limitation, I am informed by counsel that the specification must disclose an algorithm sufficient to perform the entire claimed function, not merely parts of the claimed function. That is, when the specification discloses an algorithm that only accomplishes one of multiple identifiable functions performed by a means-plus-function limitation, the specification is treated as if it disclosed no algorithm.

#### **IV. LEVEL OF ORDINARY SKILL IN THE ART**

32. I understand that the claims must be understood from the perspective of a person of ordinary skill in the art (“POSITA”) at the time of the invention. I have been informed that factors in determining the level of skill in the art include the education level of those working in the field, the sophistication of the technology, the types of problems encountered in the art, prior art solutions to those problems, and the speed at which innovations are made.

33. Taking these factors into consideration, it is my opinion that a person having ordinary skill in the art at the time of the earliest claimed priority date for the asserted patents would have had a bachelor’s degree in electrical engineering, computer engineering, computer science, or a related field, or an equivalent technical degree or equivalent work experience, and an additional two years of education or experience in computer vision software and systems. More education can supplement practical experience and vice versa.

**V. OVERVIEW OF THE ASSERTED PATENTS**

**A. The '431 Patent**

34. The '431 Patent is titled "CAMERA BASED SENSING IN HANDHELD, MOBILE, GAMING, OR OTHER DEVICES." The patent was filed on July 12, 2010 and issued April 26, 2011. The patent claims priority to July 8, 1999.

**B. The '924 Patent**

35. The '924 Patent is titled "CAMERA BASED SENSING IN HANDHELD, MOBILE, GAMING OR OTHER DEVICES." The patent was filed on March 18, 2011 and issued June 5, 2012. The patent claims priority to July 8, 1999. The patent claims it is a continuation of the application that issued as the '431 Patent, although the specification was amended on December 14, 2011 to include the Figure 18 embodiment. See '924 Patent Prosecution History, Dec. 14, 2011 Applicant Arguments/Remarks Made in an Amendment.

**C. The '079 Patent**

36. The '079 Patent is titled "MORE USEFUL MAN MACHINE INTERFACES AND APPLICATIONS." The patent was filed on December 14, 2012 and issued October 8, 2013. The patent claims priority to November 9, 1998.

**D. The '949 Patent**

37. The '949 Patent is titled "CAMERA BASED INTERACTION AND INSTRUCTION." The patent was filed on August 7, 2013 and issued November 4, 2014. The patent claims priority to May 11, 1999.



## VI. DISPUTED CLAIM TERMS

### A. “a computer means within said housing for analyzing said image to determine information concerning a position or movement of said object”

Asserted Claims	Gesture’s Proposal	Defendants’ Proposal
’431 patent cl. 7	No construction, and not governed by 35 U.S.C. § 112 ¶ 6.	<p>Means-Plus-Function Term</p> <p><u>Function</u>: “analyzing said image to determine information concerning a position or movement of said object”</p> <p><u>Structure</u>: A computer programmed to (1) scan the pixel elements in a matrix array on which said image is formed, and then calculate the centroid location “x,y” of a target on the object using the moment method disclosed in U.S. Patent No. 4,219,847 to Pinkney, as disclosed at 4:48-62; (2) add or subtract said image from prior images and identify movement blur, as disclosed at 6:64-7:14, 7:22-29; (3) obtain a time variant intensity change in said image from the detected output voltage from the signal conditioning of the camera means or by subtracting images and observing the difference due to such variation, as disclosed at 8:25-38; or (4) detect a change in color reflected from a diffractive, refractive, or interference based element on said object that reflects different colors during movement, as disclosed at 8:60-9:14.</p>

38. I understand that because the word “means” is used, there is a rebuttable presumption that the “computer means” term is governed by 35 U.S.C. § 112, ¶ 6. I understand that the presumption can be rebutted if the claim itself recites sufficient structure for performing the claimed function.

39. A person of ordinary skill in the art would not understand the claim to recite sufficient structure for performing the claimed function. While the claim refers to a “computer means,” a computer by itself was not sufficient for analyzing an image from a camera to determine information concerning a position or movement of an object positioned by a user. Rather,

computers had to be specially programmed with particular computer vision algorithms designed to analyze an image as claimed. Without such software, the computer would have been unable to perform the claimed function.

40. My understanding of this limitation is consistent with representations made by the applicant during prosecution of a parent application (App. No. 10/893,534) that a “computer means” is a means-plus-function limitation. Claim 9 of the ‘534 Application recited:

a computer means, connected to said at least one TV camera,

a) for analyzing the output of said TV camera and recognizing from the analysis a relative position of said marker with respect to the information on said board,

b) analyzing and recognizing, after a movement of said marker during the play of the game which is viewed by said TV camera, a new position of said marker with respect to the information on said board, and

c) for automatically generating, after the new position of said marker is recognized, a sensory output designed to be capable of being perceived by the person, said sensory output being different from a view of said board and marker thereon and being associated with the recognized new position of said marker with respect to the information on said board.

App. No. 10/893,534 Prosecution History, Oct. 29, 2007 Claims at Cl. 9. The functions of the “computer means” in the ‘534 Application included analyzing the output of a camera to determine position and movement information, similar to the “computer means” limitation of Claim 7 of the ’431 Patent.

41. The examiner rejected Claim 9 of the ’534 Application over the prior art, noting that “[n]ewly added limitations in a computer means phrase only represent intended use ‘for analyzing,’ ‘for recognizing,’ etc. do not specifically claim structure that would limit the apparatus claimed.” App. No. 10/893,534 Prosecution History, Jan. 24, 2008 Final Rejection at 2.

42. In response, the applicant stated:

By making this last statement, the examiner has in effect refused to give any patentable weight to the ‘function’ part of the computer ‘means.’ Such is contrary to 35 USC § 112, 6<sup>th</sup> ¶, as well as various sections of the MPEP and long established case law. As well appreciated, § 112, 6<sup>th</sup> ¶ specifically authorizes the use of ‘means or step plus function’ limitations in a claim. And when such limitations are used, it would be absurd to then ignore the ‘function’ portion as ‘only representing intended use’ as the examiner has done with the present claims.

App. No. 10/893,534 Prosecution History, Apr. 24, 2008 Notice of Appeal at 2. The applicant then argued that because the “computer means” term is a means-plus-function limitation, the prior art failed to disclose the limitation because it did not disclose each and every function. *Id.* at 2-3. The applicant went on to further note that none of the prior art disclosed a structural equivalent of the “computer means” under 35 U.S.C. § 112, ¶ 6. *Id.* at 4-5. Thus, the applicant intended for a “computer means” term similar to that claimed in the ’431 Patent to be governed by 35 U.S.C. § 112, ¶ 6.

43. Accordingly, in view of the intrinsic evidence and my understanding of the relevant field at the time of the invention, I understand the “computer means” limitation of Claim 7 of the ’431 Patent to be a means-plus-function limitation governed by 35 U.S.C. § 112, ¶ 6.

44. As to the structure, I understand that for computer-implemented means-plus-function limitations, the specification must disclose an algorithm for performing the claimed function, not just a general purpose processor. The ’431 Patent discloses a number of such algorithms.

45. While the patent discloses multiple ways of scanning, or interrogating, the pixels in an image, it only discloses one algorithm for calculating the position of an object from those scanned pixels and three algorithms for calculating the movement of an object from those scanned pixels.

46. The '431 Patent discloses that the position of an object can be calculated from an image by using the moment method disclosed in the Pinkney patent (U.S. Patent No. 4,219,847) to calculate the centroid location of the object:

As an illustration, computer 220 determines, after the array 205 has been interrogated, that the centroid "x, y" of the pixel elements on which the target image lies is at pixel  $x=500$ ,  $y=300$  (including a sub-fraction thereof in many cases). The centroid location can be determined for example by the moment method disclosed in the Pinkney patent, referenced above.

'431 Patent at 4:56-62.

47. The '431 Patent discloses three algorithms for determining information concerning the movement of an object positioned by a user. The first is to add or subtract pixel intensities of successive images and then to identify a blur in the image, the blur representing movement of the object. '431 Patent at 6:64-7:29. The second is to detect a time variant intensity change in the image as the object moves its position by subtracting images and observing the difference due to such variation for objects that "twinkle" as they move. '431 Patent at 8:4-38. The last is to detect a change in color reflected from a diffractive, refractive, or interference based element on the object that reflects different colors during movement, such that a change in color represents movement. '431 Patent at 8:60-9:14.

48. I agree with Defendants' identification of structure, which accurately captures each of these algorithms and is plainly directed to the claimed function.

49. I disagree with Gesture's identification of structure, which appears to cover any general-purpose computer, even without special programming. Gesture's construction does not limit the computer to any particular algorithm. The claimed function is not itself an algorithm. At best, it describes the input to the algorithm ("said image") and the output ("information concerning a position or movement of said object"), but it does not describe how the computer analyzes the

input to get the output, and thus does not describe an algorithm for performing the claimed function.

**B. “means for controlling a function of said apparatus using said information”**

<b>Asserted Claims</b>	<b>Gesture’s Proposal</b>	<b>Defendants’ Proposal</b>
’431 patent cl. 7	<p><u>Function</u>: “controlling a function of a handheld computer apparatus using information concerning a position or movement of at least one object positioned by a user operating said object”</p> <p><u>Structure</u>: “a control system programmed to control a function based on information concerning a position or movement of said object; and equivalents thereof”</p>	<p><u>Function</u>: “controlling a function of a handheld computer apparatus using information concerning a position or movement of at least one object positioned by a user operating said object”</p> <p><u>Structure</u>: Indefinite</p>

50. I understand the parties agree this limitation is a means-plus-function limitation to which 35 U.S.C. § 112, ¶ 6 applies. The parties also agree as to the recited function.

51. As to structure, however, I agree with Defendants that the specification does not disclose to a person of ordinary skill in the art any structure corresponding to the claimed function of a handheld device using position or movement information of an object positioned by a user.

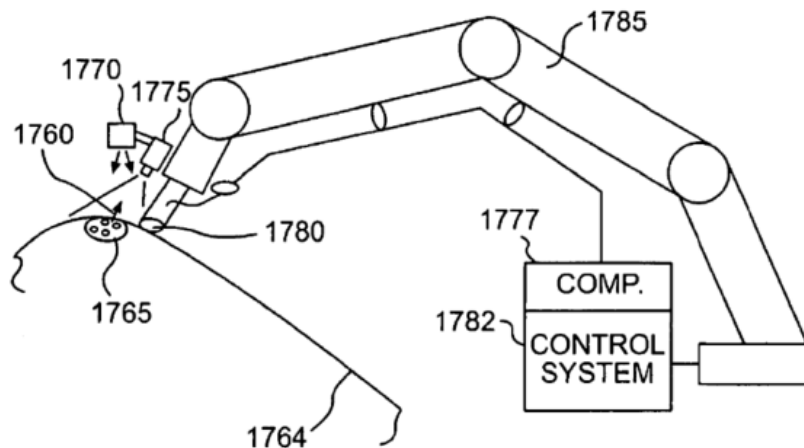
52. The patent refers to “a control system” in two instances. The first instance is a generic reference to the robustness of control systems built on pixel addressable CMOS cameras:

Given the invention, the potential for target acquisition in a millisecond or two thus is achievable with simple pixel addressable CMOS cameras coming on stream now (today costing under \$50), assuming the target points are easily identifiable from at least one of brightness (over a value), contrast (with respect to surroundings), color, color contrast, and more difficult, shape or pattern (e.g., a plaid, or herringbone portion of a shirt). This has major ramifications for the robustness of control systems built on such camera based acquisition, be they for controlling displays, or machines or whatever.

’431 Patent at 5:50-60.

53. This disclosure says nothing about using a control system to control a function of a handheld device using position or movement information of an object positioned by a user, and thus does not clearly link a control system to the claimed function.

54. The second instance is in the Figure 17B embodiment, and its accompanying description, which describes a control system wherein a robot is used for 3D acoustic imaging.



'431 Patent at FIG. 17B.

55. The patent includes the following description to accompany Figure 17B:

Consider FIG. 17B which illustrates a transducer as just described, also with automatic compensation at each point for pointing angle, robotically positioned by robot, **1785** with respect to object **1764**. In this case a projection technique such as described in U.S. Pat. No. 5,854,491 is used to optically determine the attitude of the object surface, and the surface normal direction **1760** from the position of target set **1765** projected on the surface by diode laser set **1770**, and observed by TV Camera **1775** located typically near the working end of the robot. Differences between the normal direction and the transducer propagation direction (typically parallel to the housing of the transducer) is then used by computer **1777** to correct the data of the ultrasonic sensor **1780** whose pointing direction in space is known through the joint angle encoders and associated control system **1782** of robot **1785** holding the sensor. Alternatively the pointing direction of this sensor can be monitored by an external camera such as **1710** of FIG. 17A.

It should be noted that the data obtained by TV camera 1775 concerning the normal to the surface and the surface range from the robot/ultrasonic sensor, can be used advantageously by the control system 1782 to position the robot and sensor with respect to the surface, in order to provide a fully automatic inspection of object 1764. Indeed the camera sensor operating in triangulation can be used to establish the coordinates of the exterior surface of object 1764 as taught for example in U.S. Pat. No. 5,854,491, while at the same time, the acoustic sensor can determine the range to interior points which can be differentiated by their return signal time or other means. In this manner, a complete 3D map of the total object, interior and exterior, can be obtained relative to the coordinate system of the Robot, which can then be transformed to any coordinate system desired.

'431 Patent at 25:5-35.

56. Specifically, the patent discloses that “data obtained by TV camera 1775 . . . can be used advantageously by the control system 1782 to position the robot and sensor with respect to the surface, in order to provide a fully automatic inspection of object 1764.” ’431 Patent at 25:22-27. Again, this disclosure does not describe controlling a function of a *handheld device* using *position or movement information*, but instead describes controlling a robot using unspecified data obtained by a TV camera. Thus, the patent does not clearly link a control system to the claimed function.

57. Furthermore, a control system is still not sufficient structure for performing the claimed function as it does not identify the algorithm that it is programmed with. The function of controlling a function of a handheld device using position or movement information of an object positioned by a user is a computer-implemented function. A “control system” does not connote any particular structure in the context of a handheld computer apparatus, and certainly does not bring to mind any particular structure for controlling a handheld computer apparatus using position or movement information. The closest thing to a control system in a handheld device—to the extent it may even be called a “control system”—is a processor or computer. Gesture’s proposed structure

appears to be a revised attempt to claim any computer programmed to perform the claimed function. It does not limit the control system to any particular algorithm.

58. Moreover, the claimed function is not itself an algorithm. At best, it describes the input that would be provided to the algorithm (position and movement information of an object positioned by a user operating said object), but it does not describe how the computer uses the input to control the handheld computer apparatus, and thus does not describe an algorithm for performing the claimed function. The patent does not disclose any algorithm for controlling a handheld computer apparatus using position or movement information of an object positioned by a user, nor does Gesture's proposed structure identify any such algorithm.

**C. "the detected gesture is identified by the processing unit apart from a plurality of gestures"**

Asserted Claims	Gesture's Proposal	Defendants' Proposal
'949 patent cl. 13	No construction	Plain and ordinary meaning, wherein the plurality of gestures are identified by the processing unit

59. Claim 13 recites an image capture device that comprises a device housing and processing unit. '949 patent at 16:23-40. The claim further discloses that the processing unit is adapted to both "detect a gesture has been performed," and to "correlate the gesture detected by the sensor with an image capture function and subsequently capture an image using the digital camera, wherein the detected gesture is identified by the processing unit apart from a plurality of gestures." '949 patent at 16:35-40.

60. A person of ordinary skill in the art would understand the term "the detected gesture is identified by the processing unit apart from a plurality of gestures" to mean that the processing unit must distinguish one gesture "apart from" a plurality of other gestures that it also identifies.

61. Use of the phrase "correlate the gesture detected," which is present earlier in the limitation that includes the disputed term, requires that the processing unit identify the plurality of



gestures in addition to the others it has identified. In other words, the processing unit must be able to determine what signal is present from a variety of possible signals. Defendants' proposed construction is consistent with this understanding.

62. The process of "correlation," as it was understood in the time frame of the purported patents and as it is still understood today, is well summarized in the Preface of the book "Correlation Pattern Processing" by Kumar, et al. published by Cambridge University Press in 2005, available at [https://www.google.com/books/edition/\\_/v-NhqMlrp\\_YC?hl=en&gbpv=0](https://www.google.com/books/edition/_/v-NhqMlrp_YC?hl=en&gbpv=0). This book notes that "Over the last 20 years, the basic correlation operation has improved to deal with these real-world challenges" and that the "concepts, design methods, and algorithms can be aptly summarized as correlation pattern recognition (CPR)." The Preface continues a few sentences later with "We might be satisfied with deciding which class the object belongs to, or beyond that we might want more sophisticated information about which side we are viewing the object from..." Making the connection to Claim 13 of the '949 patent even more explicit, the Preface of the book goes on to say "For many years, the testing grounds for CPR [correlation pattern recognition] have mainly been automatic target recognition (ATR) applications where correlation filters were developed to locate multiple occurrences of targets of interest (e.g., images of tanks, trucks, etc.)."

63. One example of using automatic target recognition (ATR) applications as testing grounds for CPR includes a study I co-authored in the late 1990s. *See* "Automatic Target Recognition Directed Image Compression," by Charles D. Creusere and Alan Van Nevel, published in *Journal of Aircraft*, Vol. 36, No. 4 (1999), attached as Exhibit B. There, we described the use of a hybrid algorithm that draws on automatic target recognition/automatic target cueing to select potential areas of interest to which more "bits" are allocated in compressed imagery. The

result was an image that had both areas of high resolution (areas of interest) and low resolution (contextual information). *Id.* at 626. The process by which this was achieved includes correlation filters which distinguish areas of interest from areas of non-interest. *Id.* at 627-30.

64. In other words, correlation-based processing is often used to determine the class to which an object in an image belongs: *e.g.*, tank or truck. With respect to claim 13 of the ‘949 patent, a camera is capturing imagery of a person making a gesture and the claim states that the “gesture detected” is correlated so that it can be “...identified... apart from a plurality of gestures.” In the parlance of Kumar’s book, the “detected gesture” is the “object” and the “plurality of gestures” is the set of possible classes that that “object” might belong to, with “correlation” being the process through which this determination is made.

**D. “forward facing portion” / “forward facing light source”**

Asserted Claims	Gesture’s Proposal	Defendants’ Proposal
’949 patent cls. 1, 5, 8, 13, 16	No construction	Indefinite

65. Claims 1, 8, and 13 recite “a device housing including a forward facing portion” that encompasses a digital camera and a sensor or electro-optical sensor. Claims 5 and 16 recite that the device further includes “a forward facing light source.”

66. The claims do not simply recite that the digital camera and sensor or electro-optical sensor are encompassed within the device housing, but that they are encompassed specifically within the “forward facing portion” of the housing, presumably to the exclusion of devices with such components in a backward facing portion of the housing. However, the patent specification never uses the term “forward,” let alone the phrase “forward facing,” and it does not describe how to determine which portion of a device is facing forward as opposed to backward.

67. Because the patent never uses the terms “forward” or “forward facing,” it is unclear which embodiments, if any, depict the cameras in a “forward facing portion” of the housing. For example, while the camera lenses in the Figure 1 TV monitor are located on the same side as the TV display screen, the camera lens in the Figure 7 camera is located on the opposite side of the display.

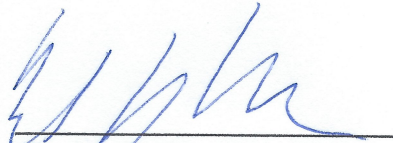
68. The prosecution history provides no further clarity on how to determine which part of a device housing is the forward facing portion. At best, the applicant only implied that a “forward facing portion” is a particular portion of the “device housing,” but without specifying how to determine which portion of the housing it is: “However, the camera handoff system 120 is not a device housing, *let alone a forward facing portion* encompassing an electro-optical sensor and a digital camera.” ’949 Patent Prosecution History, August 14, 2014 Applicant Arguments/Remarks Made in an Amendment at 8 (emphasis added).

69. Without a clear description of what the forward facing portion of a device housing is, one of ordinary skill in the art cannot determine the scope of the claims with reasonable certainty. For example, if one side of a device has a digital camera and the other side has a digital camera and an electro-optical sensor, it is unclear whether the claim limitation is met or not because one cannot determine whether the forward facing portion is the side with just the digital camera, or the side with the digital camera and electro-optical sensor.

70. The same issues apply to the “forward facing light source” term. The intrinsic evidence provides no guidance on what is “forward facing” let alone what is a “forward facing light source.” It is unclear from the intrinsic evidence how to determine whether a light source is forward facing or not, such that one of ordinary skill in the art cannot determine the scope of the claims with reasonable certainty.

I declare under penalty of perjury under the laws of the United States that the foregoing is true and correct to the best of my knowledge.

Dated: December 21, 2021

  
Charles D. Creusere, Ph.D.

# **EXHIBIT A**

## VITA

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### DISSERTATION TITLE

"Perfect Reconstruction Modulated Polyphase Filter Banks Using Reverse-Time Subfilters."

### ACADEMIC TRAINING

- 1980-1985:** University of California at Davis, B.S. in Electrical and Computer Engineering.
- 1989-1990:** University of California at Santa Barbara, M.S. in Electrical and Computer Engineering.
- 1990-1993:** University of California at Santa Barbara, Ph.D. in Electrical and Computer Engineering.

### PROFESSIONAL EXPERIENCE

**2010-Present** Holder of the Frank Carden Endowed Chair in Telemetry & Telecommunications and Full Professor. Current research interests include compressive sensing/sparse reconstruction for LIDAR and streaming sensor data as well as EEG brain analysis for audiovisual perceptual quality assessment and modeling.

**October 2008** Selected for the International Foundation for Telemetry Endowed Professorship.

**Jan. 2000-2008** Assistant/Associate professor in the Klipsch School of Electrical & Computer Engineering. My teaching areas include digital signal processing, image processing, pattern classification, and source coding (signal compression). I have done past research in areas of image, video, and audio compression as well as feature vector extraction for pattern classification. Currently, my research interests include distributed compression, polarimetric image processing for scene analysis, and nonstationary signal denoising.

**1993-1999:** Researcher & Team Leader, Naval Air Warfare Center, China Lake. My research efforts have focused on high speed image and video compression technologies which offer unique capabilities such as robustness to transmission errors and regional localization. My team (2 other people) and I have implemented a real-time (3 to 15 frames/second with 240x512 frames)

320C80-based system which uses a wavelet transform along with embedded coding techniques to compress a video input and stream it through the Internet via TCP/IP protocols. Our recent research focus has been to add more intelligence to the encoder so that the space-frequency information in the image that is most useful for image analysis is received with the highest fidelity. While most of my recent research has been in the area of embedded compression, I am still very much interested in other applications of time/space-frequency decompositions and of multirate digital signal processing concepts in general.

**1999, Spring Quarter:** Instructor at the University of California at Santa Barbara. Taught graduate class in Multirate Digital Signal Processing, ECE 258B.

**1990-1993:** Research Assistant, Department of Electrical and Computer Engineering, University of California, Santa Barbara. Worked under Prof. S.K. Mitra on subband coding and multirate filter bank theory. Also implemented real-time filter banks on a Motorola 56001 digital signal processor.

**1992:** Summer Employee, AT&T Bell labs, Murray Hill, NJ. Developed and simulated new methods of extremely low bit rate video coding for video telephone applications.

**1985-1989:** Design Engineer, Naval Weapons Center, China Lake. Designed, built, and tested the guidance electronics for the Laser Guided Training Round. This project included mixed analog and digital circuit design as well as the programming of an embedded DSP. Also developed software for an advanced video processor and studied ground target tracking.

#### FUNDED RESEARCH

- (2000) Office of Naval Research, *Compression of Digital Elevation Maps Using Non-linear Wavelets*, 2000-2003, \$94K
- (2001) Sandia National Labs, *Intelligent Compression for Remote Sensing*, 2001-2003, \$70K.
- (2002) National Science Foundation (Early Career Grant), *Efficient Audio Compression with Perceptually Embedded Scalability*, 2002-2007, \$350K.
- (2004) National Geospatial-Intelligence Agency, *Passive Polarimetric Imagery Classification Study*, 2004-2006, \$160K (joint with Dr. David Voelz).
- (2005) Los Alamos National Laboratories, *Signal Detection via Adapted Filter Banks and Geometric Dimensionality Reduction*, 2005-2006, \$15K (unburdened).
- (2006) Los Alamos National Laboratories, *Signal Detection via Adapted Filter Banks and Geometric Dimensionality Reduction*, 2006-2007, \$50K (unburdened).
- (2006) National Geospatial-Intelligence Agency, *Exploiting Polarization in Imaging Systems*, 2006-2009, \$304K (joint with Dr. David Voelz).
- (2006) Army Research Office, *Distributed Source Coding Using Bitstream-based Detection and Classification*, 2006-2009, \$326K.
- (2006) DARPA (Subcontract from LANL), *ADAM Project*, 2006-2007, \$104K (joint with Dr. Joe Lakey and Dr. Jaime Ramirez)

- (2009) NMSU IRG, *Perceptual audio quality evaluation by direct measurement of human brain responses*, 2009-2010, \$39K (joint with Dr. Jim Kroger, Psychology)
- (2011) National Science Foundation, *CIF:Medium:Assessment and modeling of temporal variation in perceived audio and video quality using direct brainwave measurement*, 2011-2015, \$917K (lead PI with Dr. Jim Kroger and Dr. Joerg Kliewer as co-PIs)
- (2011) NASA EPSCOR, *Proximity Operations for Near Earth Asteroid Exploration*, 2011-2014, \$750K (co-PI, with Dr. Eric Butcher (lead), others)
- (2012) National Geospatial Intelligence Agency (NGA), *Pulse Complexity Based LIDAR Scene Modeling for Sparse Reconstruction and Super-Resolution*, 2012-2013 (plus 3 1 year options), \$150K (\$75K/option year), co-PI Dr. David Voelz.
- (2018) Airforce Research Lab (AFRL), *Software Radio Design in LabView FPGA*, 2018-2019, \$140K.

### **PATENTS**

- Patent titled "Parallel digital image compression system which exploits zerotree redundancies in wavelet coefficients," Patent Number 6,148,111.
- Patent titled "Efficient embedded image and video compression using lifted wavelets," Number: 6,466,698, granted October 15, 2002.

### **OTHER DISTINCTIONS**

- Awarded the International Foundation for Telemetering Professorship, October 2008.
- Received an educational fellowship from the Department of Defense, 1989-1992.
- Certificate of Merit for the outstanding technical paper awarded at the AIAA Missile Sciences Conference for the paper "Automatic target recognition directed image compression," Nov. 1998.
- Patent (classified) "Notice of Allowability" titled, "Microcontroller-Based Laser Pulse Decoder," granted October 7, 1991.
- Associate editor for IEEE Trans. on Image Processing, 2002-2005, 2010-2014
- Associate editor for IEEE Trans. on Multimedia, 2008-2013.
- Guest Editor, "Issue on Advances in Hyperspectral Data Processing and Analysis", IEEE Journal of Selected Topics in Signal Processing, Vol. 5, Numbers: 5 & 6, August-September 2015,
- Co-general chair, IEEE Digital Signal Processing Workshop, August 2004, Taos, NM.
- Co-technical chair for the 2012 and 2014 Southwest Symposium on Image Analysis and Interpretation.
- Student Paper Contest Chair, 40th Asilomar Conf. on Signals, Systems, and Computers, October 2006.



- Organized special session entitled "Applications of Multirate DSP" at the 40th Asilomar Conf. on Signals, Systems, and Computers, October 2006.
- Member of technical program committees for the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), the IEEE International Conference on Image Processing (ICIP), and the IEEE Data Compression Conference (DCC).
- Senior Area Editor, IEEE Transactions on Image Processing, March 2016 to present.
- 

### **CONSULTING ACTIVITIES**

- Video compression systems (technology consultant), Abba Tech, Albuquerque, NM, 2000.
- Expert witness in laser rangefinding technology, Asia Optical Inc. (through NY law firm of Osterlenk, Faber, Gerb & Soffen), Case: LTI versus Nikon/AOI, July 2001-2003. Case went to trial/testified in court.
- Technical expert for defense; Case: Real-Time v. AT&T (byte.mobile), 2011-2012, case settled June 2012.
- Technical expert for defense; Case: Princeton Digital v. Dell, 2014-2015, case dismissed June 2015.
- Technical expert for defense; Noninfringement & IPR (6,597,812), Real-time v. SAP, 1/2016-6/2016.
- Technical expert for defense; IPRs (7,378,992 & 7,415,530), Real-time v. Riverbed, 2/2016-2017
- Technical expert for defense; IPRs (8,643,513, 7,378,992, 7,161,506, & 9,054,728), Real-time v. Dell, 2/2016-2017
- Technical expert for defense; Noninfringement, Real-time v. HP Enterprises, 4/2016-2018.
- Technical expert for defense; IPR (7,358,867, 7,161,506, & 9,054,728), Real-time v. Teradata 11/2016-2017
- Technical expert for defense; IPRs (8,643,513 & 7,378,992), Real-time v. Veritas 12/2016-2017.
- Technical expert for defense; IPRs (7,075,917 & 6,304,612), UNILOC v. Apple 9/2018-2019.
- Technical expert for defense; IPR (7,558,730), Advanced Voice Recognition Systems v. Apple 7/2019-2020.
- Technical expert for defense; District Court; Noninfringement, Realtime Adaptive Systems v. YouTube/Google, 2018-2020.
- Technical expert for defense; ITC case; Nokia v. Lenovo, Oct. 2020-2021.
- Technical expert for defense; IPR (10,176,848), Maxell v. Apple, 2019-2021.
- Technical expert for plaintiff; District Court; USAA v. PNC Bank, 2021-present.
- Technical expert for defense; District Court; Gesture Tech Partners v. Apple/Lenovo/Motorola, 2021-present.

## JOURNAL PUBLICATIONS

1. **C.D. Creusere and S.K. Mitra**, "A simple method for designing high-quality prototype filters for M-band pseudo-QMF banks," *IEEE Trans. on Signal Processing*, Vol. 43, No. 4, April 1995, pp. 1005-1007.
2. **C.D. Creusere and S.K. Mitra**, "Efficient audio coding using perfect reconstruction noncausal IIR filter banks," *IEEE Trans. on Speech and Audio Processing*, Vol. 4, No. 2, March 1996, pp. 115-123.
3. **C.D. Creusere and S.K. Mitra**, "Image coding using wavelets based on perfect reconstruction IIR filter banks," *IEEE Trans. on Circuits and Systems for Video Technology*, Vol. 6, No. 5, Oct. 1996, pp. 447-458.
4. **C.D. Creusere**, "A new method of robust image compression based on the embedded zerotree wavelet algorithm," *IEEE Trans. on Image Processing*, Vol 6, No. 10, Oct. 1997, pp. 1436-1442.
5. **C.D. Creusere and A. Van Nevel**, "ATR-directed image and video compression," *Journal of Aircraft*, Vol. 36, No. 4, pp. 626-31, July-August 1999.
6. **C.D. Creusere**, "Fast embedded compression for video," *IEEE Trans. on Image Processing*, Vol. 8, No. 12, pp. 1811-16, December 1999.
7. **C.D. Creusere**, "Motion compensated video compression with reduced complexity encoding for remote transmission," *Signal Processing: Image Communications*, Vol. 16, pp. 627-42, April 2000.
8. **C.D. Creusere**, "Understanding perceptual distortion in MPEG scalable audio coding," *IEEE Trans. on Speech and Audio Processing*, Vol. 13, No. 3, pp. 422-431, May 2005.
9. **L. E. Boucheron and C.D. Creusere**, "Lossless wavelet-based compression of digital elevation maps for fast and efficient search and retrieval," *IEEE Trans. on Geoscience and Remote Sensing*, Vol. 43, No. 5, pp. 1210-1214, May 2005.
10. **V. Thilak, D. Voelz, and C.D. Creusere**, "Polarization-based index of refraction and reflection angle estimation for remote sensing applications," *Applied Optics*, Vol. 46, Bo. 30, pp. 7427-7536, Oct. 2007.
11. **C.D. Creusere, K. Kallakuri, and R. Vanam**, "An Objective Metric of Human Subjective Audio Quality Optimized for a Wide Range of Audio Fidelities," *Audio, Speech, and Language Processing, IEEE Transactions on [see also Speech and Audio Processing, IEEE Transactions on]*, vol.16, no.1, pp.129-136, Jan. 2008
12. **S. Kandadai and C.D. Creusere**, "Scalable Audio Compression at Low Bitrates," *Audio, Speech, and Language Processing, IEEE Transactions on [see also Speech and Audio Processing, IEEE Transactions on]*, vol.16, no.5, pp.969-979, July 2008
13. **S. Kandadai and C.D. Creusere**, "Reverse engineering and repartitioning vector quantizers using training set synthesis," *Signal Processing*, August 2008.
14. **V. Thilak, C.D. Creusere, and D. Voelz**, "Passive Polarimetric Imagery-Based Material Classification Robust to Illumination Source Position and Viewpoint," *Image Processing, IEEE Transactions on*, vol.20, no.1, pp.288-292, Jan. 2011.
15. **C.D. Creusere and J. Hardin**, "Assessing the Quality of Audio Containing Temporally Varying Distortions," *Audio, Speech, and Language Processing, IEEE Transactions on*, vol.19, no.4, pp.711-720, May 2011.
16. **Castorena, J.; Creusere, C.D.**, "The Restricted Isometry Property for Banded Random Matrices," *Signal Processing, IEEE Transactions on*, vol.62, no.19, pp.5073-5084, Oct.1, 2014 doi: 10.1109/TSP.2014.2345350.
17. **Castorena, J.; Creusere, C.D.**, "Sampling of Time-Resolved Full-Waveform LIDAR Signals at Sub-Nyquist Rates," *Geoscience and Remote Sensing, IEEE Transactions on*, vol.53, no.7, pp.3791-3802, July 2015. doi: 10.1109/TGRS.2014.2383839.

## REFEREED CONFERENCE PUBLICATIONS

1. **H. Babic, S.K. Mitra, C.D. Creusere, and A. Das**, "Perfect reconstruction recursive QMF banks for image subband coding," *Proc. Asilomar Conf. Signals, Systems, and Computers*, Pacific Grove, CA, Nov. 1991, pp. 746-750.
2. **S.K. Mitra, C.D. Creusere, and H. Babic**, "A novel implementation of perfect reconstruction QMF banks using IIR filters," *Proc. IEEE Int. Symposium on Circuits and Systems*, San Diego, CA, May 1992, pp. 2312-2315.
3. **S.K. Mitra, C.D. Creusere, and H. Babic**, "Design of transmultiplexers using IIR filter banks," *Signal Processing VI: Theories and Applications*, Elsevier Science Publishers, 1992, pp. 223-226.
4. **C.D. Creusere and S.K. Mitra**, "Efficient image scrambling using polyphase filter banks," *Proc. International Conference on Image Processing*, Austin, TX, Nov. 1994, pp. 81-85.
5. **C.D. Creusere and G. Hewer**, "Wavelet-based nearest neighbor pattern classification using scale sequential matching," *Proc. Asilomar Conf. Signals, Systems and Computers*, Pacific Grove, CA, Nov. 1994, pp. 1123-1127.
6. **C.D. Creusere**, "Embedded zerotree image coding using low complexity IIR filter banks," *Proc. Int. Conf. on Acoustics, Speech, and Signal Processing*, Detroit, MI, May 1995, pp. 2213-16.
7. **C.D. Creusere and Gary Hewer**, "Digital video compression for weapons control and bomb damage indication," *AGARD Conference Proceedings 576*, Chapter 16, Sept. 1995.
8. **C.D. Creusere**, "Image coding using parallel implementations of the embedded zerotree wavelet algorithm," *Proc. of the Digital Video Compression Conference (Algorithms and Technologies 1996)*, San Jose, CA, Jan. 28-Feb. 2, 1996, pp. 82-93.
9. **C.D. Creusere**, "A family of image compression algorithms which are robust to transmission errors," *Proceedings of the SPIE*, Vol. 2825, Denver, CO, August, 1996, pp. 890-900.
10. **C.D. Creusere**, "Perfect reconstruction time-varying IIR filter banks," *Conf. Rec. Asilomar Conf. Signals, Systems, and Computers*, Pacific Grove, CA, Nov. 1996, pp. 1319-23.
11. **C.D. Creusere**, "Out-of-loop motion compensation for reduced complexity video encoding," *Proc. of the Data Compression Conf.* (pp. 428) & *Data Compression Industry Workshop* (pp.28-37), March 1997, Snowbird, UT.
12. **C.D. Creusere**, "Periodic pan compensation for reduced complexity video compression," *Proc. Int. Conf. on Acoustics, Speech, and Signal Processing*, Vol IV, pp. 2889-92, April 1997, Munich, Germany.
13. **C.D. Creusere**, "A new approach to global motion compensation which reduces video encoding complexity," *Proc. Int. Conf. on Image Processing*, Vol. III, pp. 634-7, October 1997, Santa Barbara, CA.
14. **C.D. Creusere**, "Spatially partitioned lossless image compression in an embedded framework," *Conf. Rec. 31st Asilomar Conf. on Signals, Systems, and Computers*, Nov. 1997, Pacific Grove, CA.
15. **C.D. Creusere**, "Adaptive embedding for reduced complexity image and video compression," *Proc. of the SPIE*, Vol 3309 (Visual Communications and Image Processing), pp. 48-57, Jan. 1998, San Jose, CA.
16. **C.D. Creusere**, "Successive coefficient refinement for embedded lossless image compression," *Proc. of the Data Compression Conf.*, pp. 539, March 1998, Snowbird, UT.
17. **C.D. Creusere**, "Subband coding of speech and audio," *Proc. of the European Signal Processing Conf.* (invited paper), Sept. 1998, Isle of Rhodes, Greece.
18. **C.D. Creusere**, "Fast embedded video compression using cache-based processing," *Proc. of the*

*European Signal Processing Conf.*, Sept. 1998, Isle of Rhodes, Greece.

19. **C.D. Creusere**, "Successive coefficient refinement for embedded lossless image compression," *Proc. Int. Conf. on Image Processing*, Oct. 1998, Chicago, IL.
20. **C.D. Creusere** and A. Van Nevel, "Autonomous target recognition directed image compression," *Proc. of the AIAA*, Nov. 1998.
21. **C.D. Creusere**, "Improved successive refinement for wavelet-based embedded image compression," *Proc. of the SPIE*, Denver, CO, July 1999.
22. A. Van Nevel and **C.D. Creusere**, "Intelligent Bandwidth Compression," *Proc. of the SPIE*, Denver, CO, July 1999.
23. **C.D. Creusere**, "Optimal refinement/significance map tradeoffs in SPIHT-based image compression," *Conf. Rec., 34<sup>th</sup> Asilomar Conf. on Signals, Systems, & Computers*, pp. 1026-30, Oct. 2000.
24. **C.D. Creusere**, "Compression of digital elevation maps using nonlinear wavelets," *Proc. Int. Conf. on Image Processing*, pp. 824-7, October 2001.
25. **C.D. Creusere and G. Dahman**, "Object detection and localization in compressed video," *Conf. Rec. 35th Asilomar Conf. on Signals, Systems, and Computers*, Nov. 2001, Pacific Grove, CA.
26. **C.D. Creusere**, "An analysis of perceptual artifacts in MPEG scalable audio coding," *Proceedings of the Data Compression Conference*, pp. 152-161, April 2002, Snowbird, UT.
27. **C.D. Creusere and N. Tolk**, "Combining wavelets and GLICBAWLS to achieve resolution-progressive lossless compression," *Proc. of the International Conference on Image Processing*, pp. III-229-32, October 2002.
28. **L. Boucheron and C.D. Creusere**, "Compression of digital elevation maps for fast and efficient search and retrieval," *Proc. of the International Conference on Image Processing*, pp. 629-32, September 2003.
29. **S. Kandadai and C.D. Creusere**, "An experimental study of object detection in the wavelet domain," *Conf. Rec. 37th Asilomar Conf. on Signals, Systems, and Computers*, pp. 1620-4, Nov. 2003, Pacific Grove, CA.
30. **C.D. Creusere**, "Quantifying perceptual distortion in scalably compressed MPEG audio," *Conf. Rec. 37th Asilomar Conf. on Signals, Systems, and Computers*, pp. 265-9, Nov. 2003, Pacific Grove, CA.
31. **C.D. Creusere and L. Zhou**, "Spatial object detection and classification in JPEG bitstreams," *Proceedings 11<sup>th</sup> Digital Signal Processing Workshop*, pp. 115-9, August 2004, Taos Ski Valley, NM.
32. **L. Zhou and C.D. Creusere**, "Spatial object detection in JPEG bitstreams," *Proceedings European Conference on Signal Processing*, pp. 949-52, September 2004, Vienna, Austria.
33. **V. Thilak and C.D. Creusere**, "Tracking of extended size targets in H.264 compressed video using the probabilistic data association filter," *Proceedings European Conference on Signal Processing*, pp. 281-4, September 2004, Vienna, Austria.
34. **S. Kandadai and C.D. Creusere**, "Reverse engineering vector quantizers by training set synthesis," *Proceedings European Conference on Signal Processing*, pp. 789-92, September 2004, Vienna, Austria.
35. **V. Thilak, J. Saini, D. G. Voelz, C. D. Creusere**, "Pattern recognition for passive polarimetric data using nonparametric classifiers," *Proc. of the SPIE Vol. 5888*, p. 337-344, Polarization Science and Remote Sensing II; Joseph A. Shaw, J. Scott Tyo; Eds.
36. **R. Vanam and C.D. Creusere**, "Evaluating low bitrate scalable audio quality using advanced version of PEAQ and energy equalization approach," *Proc. IEEE Int. Conf. on Acoustics, Speech, and Signal Processing*, Vol. III, pp. 189-92, March 2005.
37. **S. Kandadai and C.D. Creusere**, "Reverse engineering vector quantizers for repartitioned

signal spaces," *Proc. 39<sup>th</sup> Asilomar Conference on Signals, Systems, and Computers*, pp. 1208-12, Pacific Grove, CA, Nov. 2005.

38. **R. Vanam and C.D. Creusere**, "Scalable perceptual metric for evaluating audio quality," *Proc. 39<sup>th</sup> Asilomar Conference on Signals, Systems, and Computers*, pp. 319-23, Pacific Grove, CA, Nov. 2005.

39. **S. Kandadai and C.D. Creusere**, "Perceptually-weighted audio coding that scales to extremely low bitrates," *Proc. IEEE Data Compression Conference*, pp. 382-391, Snowbird, UT, March 2006.

40. **V. Thilak, D. Voelz, C. Creusere, S. Damarla**, "Estimating the refractive index and reflected zenith angle of a target using multiple polarization measurements," *Proc. SPIE Vol. 6240, 624004*, Polarization: Measurement, Analysis, and Remote Sensing VII; Dennis H. Goldstein, David B. Chenault; Eds., May 2006.

41. **V.M. Prasad and C.D. Creusere**, "Analyzing reversible lapped transformations using Reng probing," *Proc. 40<sup>th</sup> Asilomar Conference on Signals, Systems, and Computers*, pp. 873-877, Oct. 2006.

42. **N. Balachandran and C.D. Creusere**, "Chirp classification using hidden Markov models," *Proc. 40<sup>th</sup> Asilomar Conference on Signals, Systems, and Computers*, pp. 545-549, Oct. 2006.

43. **V. Thilak and C.D. Creusere**, "Estimating the complex index of refraction and view angle of an object using multiple polarization measurements," *Proc. 40<sup>th</sup> Asilomar Conference on Signals, Systems, and Computers*, pp. 1067-1071, Oct. 2006.

44. **V. Thilak, C.D. Creusere, and D.G. Voelz**, "Material classification using passive polarimetric imagery," *Proc. IEEE Int. Conf. on Image Proc.*, Vol. 4, pp. IV-121-124, Sept., 2007.

45. **A. Pamba, V. Thilak, D. G. Voelz, C. D. Creusere** "Estimation of incidence and reflection angles from passive polarimetric imagery: extension to out-of-plane scattering," *Proc. SPIE Vol 6682, 668200*, Polarization Science and Remote Sensing III, Joseph A. Shaw; J. Scott Tyo, Editors, September 2007.

46. **V. Thilak, D. G. Voelz, C. D. Creusere**, "Image segmentation from multi-look passive polarimetric imagery," *Proc. SPIE 6682, 668206*, Polarization Science and Remote Sensing III, Joseph A. Shaw; J. Scott Tyo, Editors, October 2007.

47. **S. Kandadai and C.D. Creusere**, "Optimal Bit Layering for Scalable Audio Compression Using Objective Audio Quality Metrics," *Signals, Systems and Computers, 2007. ACSSC 2007. Conference Record of the Forty-First Asilomar Conference on*, pp.560-564, 4-7 Nov. 2007.

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# **EXHIBIT B**

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# Automatic Target Recognition Directed Image Compression

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A novel synthesis is presented of two separate areas of image processing: automatic target recognition/cueing (ATR/ATC) and embedded image compression. To maximize the information content of a transmitted image, an ATR algorithm is used to detect potential areas of interest, and the compression algorithm regionally compresses the image, allocating more bits to the areas of interest. In this fashion, contextual information is retained, albeit at a lower resolution. Higher information content is achieved at a lower bit rate.

## I. Introduction and Background

AS the number of operational uncrewed aerial vehicles (UAVs) and uncrewed aerial combat vehicles (UCAVs) increases, the availability of sufficient communications bandwidth will become a major concern. Whereas command and control signals require a small portion of the available bandwidth, high-resolution imagery and video can easily consume all of the available bandwidth and more. Unfortunately, tactical datalinks such as link 16 or SATCOM only support data rates of 57 kbit/s (with error correction) and 4.8 kbit/s, respectively, whereas other high-speed systems such as common datalink have significant limitations on the number of simultaneous users allowed. To increase the number of systems that can operate simultaneously using the limited rf bandwidth available, one must adopt digital compression. However, compression results in degraded imagery at the receiver for reasonable compression ratios ( $>2:1$ ). With these severe limitations on the bandwidth in mind, we have developed a hybrid algorithm that draws on automatic target recognition/automatic target cueing (ATR/ATC) algorithms and regional embedded compression techniques.

The basic idea of the algorithm is relatively simple. Whereas an image may contain several different objects (trucks, buildings, tanks, etc.), only a few may be of potential interest to a military observer. An ATR algorithm is used to select potential areas of interest, which are then fed to a compression algorithm that regionally compresses the image, allocating more bits to the areas of interest. This process results in an image that has areas of high resolution (potential targets) and areas of low resolution in which contextual information is retained. Overall, a high-compression ratio can be achieved while maximizing information content.

UAVs are a platform for which this technology could be extremely useful. By placing an ATR/ATC directed compression system on a UAV, the reduction in bandwidth usage would enable more aircraft to effectively communicate over a limited channel. Furthermore, the ATR/ATC would also reduce the workload of UAV operators and imagery analysts, by providing areas of potential interest automatically. In a different context, the regional compression algorithms could be used to upload data to aircraft in flight, preserving features of interest in the imagery at high resolution, while still retaining contextual information, albeit at a lower resolution. A possible application in this sense would be for uploading imagery that provides funnel features for navigation. Currently within the military, there is a desire for imagery in the cockpit, and this goal can be achieved for preplanned missions. However, the communication channels avail-

able to tactical aircraft are ill suited for uploading imagery to an aircraft in flight. ATR directed regional compression can alleviate this problem.

In the first section, we will describe the ATR algorithm, developed by Carlson,<sup>1</sup> Mahalanobis et al.,<sup>2,3</sup> and Vijaya Kumar et al.,<sup>4</sup> which we use to determine the regions of interest. In the following sections, we will describe the embedded zerotree wavelet (EZW) algorithm and how it has been adapted for spatially variant resolution. In the last sections we present some results and discuss potential applications and future directions.

## II. Maximum Average Correlation Height Filters

### A. Mathematical Overview

To maximize the information content sent over the available bandwidth, we have chosen to identify potential regions of interest. To accomplish this, we have implemented a class of correlation filters as developed by Mahalanobis et al.<sup>2,3</sup> These filters have exceptional tolerance to scaling and rotation distortions. The tolerance of the filters is incorporated through the selection of an appropriate training set and can be tuned to provide high (generalization) or low (specificity) tolerance.

In the discussion of the maximum average correlation height (MACH) filters that follows, a bold lower case symbol indicates a column vector, whereas a bold upper case symbol represents a diagonal matrix. The filters result from maximizing the ratio

$$J(\mathbf{h}) = |\mathbf{h}^+ \mathbf{m}| / \mathbf{h}^+ \mathbf{S} \mathbf{h} \quad (1)$$

where  $\mathbf{h}$  is the correlation filter and  $\mathbf{m}$  is the average of the training images in the Fourier domain. Each image is lexicographically ordered to form a vector.  $\mathbf{S}$  is the average similarity measure matrix

$$\mathbf{S} = \sum_{k=1}^N (\mathbf{X}_k - \mathbf{M})(\mathbf{X}_k - \mathbf{M})^+ \quad (2)$$

In Eq. (2)  $\mathbf{X}_k$  are the individual training images, again in the Fourier domain. The training image is lexicographically ordered, and its elements placed on the diagonal of  $\mathbf{X}_k$ , whereas  $\mathbf{M}$  is the mean training image, arranged similarly to  $\mathbf{X}_k$ . Furthermore, all of the processing to generate the filters is performed in the Fourier domain to gain translational invariance. It is possible to perform the processing in other domains, for example, wavelet or spatial, but care must be taken to properly register the training imagery.

The optimal filter  $\mathbf{h}$  is then given by

$$\mathbf{h} = \mathbf{S}^{-1} \mathbf{m} \quad (3)$$

Variants on the MACH filter can be achieved by varying the performance metric one wishes to maximize. For example, Refregier<sup>5</sup> has developed optimal tradeoff synthetic discriminant filters (OTSDFs) that attempt to minimize the energy functional

$$E(\mathbf{h}) = \mathbf{h}^+ \mathbf{Q} \mathbf{h} - \delta |\mathbf{h}^+ \mathbf{m}| \quad (4)$$

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where

$$Q = \alpha P + \beta D + \gamma S \quad (5)$$

$S$  is as defined previously,  $P$  is the power spectral density of the expected noise, and  $D$  is the average power spectral density of the training set. The constants  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  are nonnegative and must satisfy  $\alpha^2 + \beta^2 + \gamma^2 + \delta^2 = k$ , where  $k$  is any positive constant. Minimizing  $E(h)$  results in

$$h = (\delta/2)Q^{-1}m \quad (6)$$

By varying the parameters, one can optimize filter performance for the situation under study. If one sets  $\alpha = \beta = 0$ , the result is the MACH filter discussed earlier. Further variations can be made to the basic idea, including the extension to multiple class discrimination using distance classifier correlation filters, which are able to distinguish between multiple classes of similar objects, for example, T72s vs M1A1 tanks.

The class of MACH filters was chosen for the feature detection for several reasons. As discussed, the filters can incorporate varying degrees of distortion tolerance and can be built to generalize classes of targets. Another benefit of the algorithm is that the result is statistically optimum and depends on a realistic, mathematically rigorous optimization procedure as opposed to other heuristic methods. A final consideration is the computational efficiency. The MACH filters require no segmentation or edge detection preprocessing, and the correlation step can be performed rapidly using dedicated fast Fourier transform hardware.

### B. MACH Implementation

To implement the MACH filters, one must first decide on a representative training set. Typically, the training set consists of  $N < 20$  images collected from varying perspectives. A training set of one image will result in a filter similar to the matched filter with no distortion tolerance, whereas a training set having dozens of perspectives and scalings will produce a filter with a broad response and low discrimination properties. The filter  $h$  is first calculated offline from the training data. If one is using the OTSDFs, some parameter tuning can be performed at this point to maximize the correlation peaks for the training data.

Following correlation of an input test scene with  $h$ , the correlation scene must be processed to determine the areas of interest. Previous correlation filters<sup>6-8</sup> had placed constraints on the correlation height, and classification was then accomplished by comparing the correlation height of the test scenes to the constraint. Generally, a threshold must be set when using the correlation height as a metric for detection and/or classification. By changing this threshold one can trade off between the probability of detection and the probability of false alarms, a lower threshold allowing more false alarms and a higher threshold reducing the probability of detection.

A second metric that can be used is the peak-to-sidelobe ratio (PSR). A square window ( $1 \times 1$ ,  $3 \times 3$ ,  $5 \times 5$ , ...) is chosen and

centered around the correlation peak, and the energy within this window is calculated. The energy in a larger square window is also calculated, and the ratio of the two energies is the PSR. This ratio can then be compared to a threshold for detection and classification. The local energy percentage can be modified to allow for multiple target possibilities by selecting multiple windows based on correlation height and excluding these energies from the global energy calculation. The benefit of this approach is that the ratio is independent of illumination or amplification effects. The overall peak height can be affected by constant amplification, but the ratio will remove this problem. This metric works well in rejecting false peaks due to clutter because most correlation surfaces for clutter images will not contain a high percentage of energy in a localized window.

In our hybrid algorithm, the second metric was chosen to determine regions of interest. No hard thresholding was used for detection. Instead, the top three energy percentage locations were selected as potential regions of interest to be compressed at a higher resolution than the background. The choice of three targets is somewhat arbitrary and can be changed based on the application. If a large number of areas are desired at high resolution, it may impact how the coding of the side information is performed. The choice may also be eliminated completely with the use of thresholding to eliminate false alarms and to increase the probability of detection. In this demonstration it was sufficient to designate a number of potential targets to effectively illustrate the concept.

### III. EZW Compression

At the core of our feature-based approach to compression is an embedded coding algorithm. In this method of compression, data are transmitted to the receiver in order of importance, that is, the data that most reduces the error between the reconstructed image and the original image is sent first. This concept is shown in Fig. 1. There are a number of advantages to embedded compression algorithms: fixed bit rates, for example, compression ratios, are easily achieved; unequal transmission error protection is trivial; and inherently robust bit streams can be created.

The fundamental observation that inspired the EZW algorithm<sup>9</sup> is that there is a strong correlation between insignificant coefficients at the same spatial locations in different wavelet scales; that is, if a wavelet coefficient at a coarser scale is zero, then it is more likely that the corresponding wavelet coefficients at finer scales will also be zero. Figure 2 shows a three-level, two-dimensional wavelet decomposition and the links that define a single zerotree (the quadtree data structure containing all of the coefficients corresponding to a given region of the original image). If a wavelet coefficient at a given scale is zero along with all of its descendants (as shown in Fig. 2), then a special zerotree-root (ZTR) symbol is transmitted, eliminating the need to transmit the values of the descendants. Note that ZTR symbols can be created at any level of the wavelet coefficient mapping. Thus, if one of the three zerotree children at level  $s_2$  in Fig. 2 is significant for a given bit plane while the others are not, then the

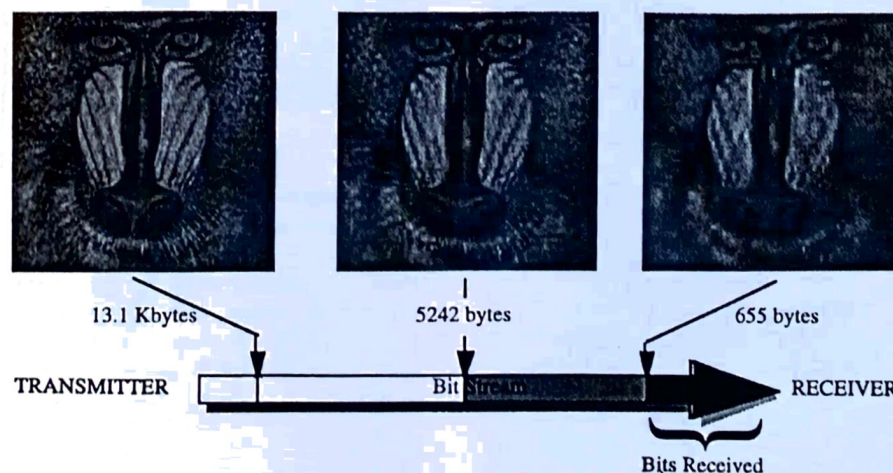


Fig. 1 Embedded image compression.



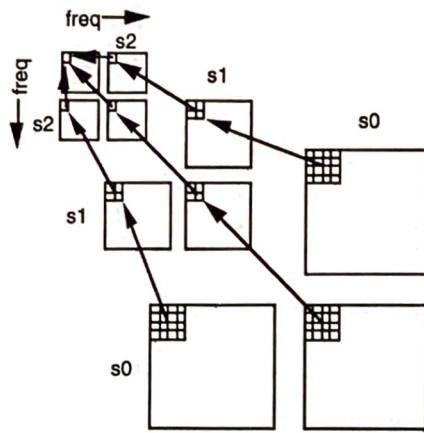


Fig. 2 Wavelet coefficient mapping with one complete zerotree shown.

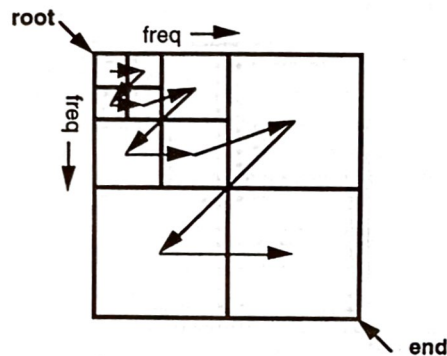


Fig. 3 Scanning order of wavelet coefficients.

low-frequency root coefficient must be represented by an isolated zero (IZ) symbol (assuming that it is also insignificant) while the two insignificant children are represented with ZTR symbols. Note that the wavelet scale ( $s_0$ ,  $s_1$ , etc.) is inversely proportional to the spatial frequency. Basically, one can view this redundancy extraction process as a multiresolutional, self-terminating run-length encoder. Regardless of how one views it, zerotrees exploit the correlation of insignificance across scales and decrease the number of symbols that must be processed by the arithmetic encoder and transmitted to the receiver.

To generate an embedded code (where information is transmitted in order of importance), the algorithm scans the wavelet coefficients in what is basically a bit-plane fashion. First, a starting threshold is selected that is at least one-half as large as the magnitude of the largest wavelet coefficient. If the starting threshold is selected to be a power of 2, then a very fast approach can be used to compute all of the zerotree dependencies in one pass through the wavelet coefficients.<sup>10</sup> Starting with the appropriate threshold, the algorithm sweeps through the coefficients from low- to high-frequency subband as shown in Fig. 3, transmitting the sign (+ or -) if a coefficient's magnitude is greater than the threshold (i.e., it is significant), either a ZTR, if it is less than the threshold and the root of a zerotree at the coarsest possible scale, or an IZ, otherwise; this is the dominant pass. Next for the subordinate pass, all coefficients deemed significant in the dominant pass are added to a second subordinate list that is itself scanned. For each coefficient on this list during the pass, 1 bit is transmitted, decreasing its approximation error in the decoder by one-half (the coefficient's absolute error during a given pass depends on the value of the starting threshold). One iteration of this successive refinement process is shown in Fig. 4. The threshold is then halved, and the two passes are repeated with those coefficients having been previously found significant being replaced by zeros in the dominant pass (so that they do not inhibit the formation of future zerotrees). The symbol stream created by this scanning process is then passed through an arithmetic encoder to eliminate any remaining statistical redundancy before transmission to the decoder. A block diagram of the complete process is shown in

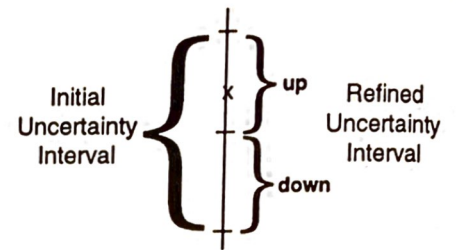
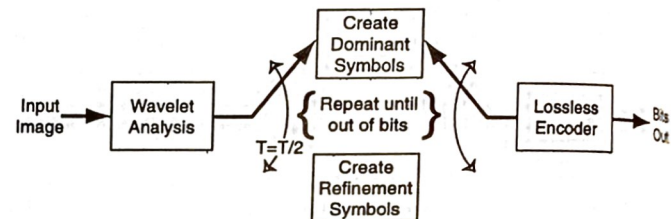
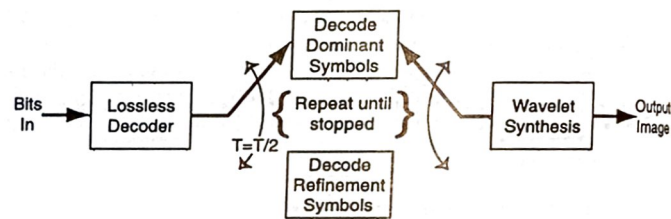


Fig. 4 One iteration of the successive refinement process.



a) Encoder



b) Decoder

Fig. 5 Embedded image.

Fig. 5a. To estimate symbol probabilities for the arithmetic encoder and decoder, we use the simple single-context, backward-adaptive model presented by Witten et al.<sup>11</sup> Slightly better compression can be achieved using the multicontext model proposed by Shapiro<sup>9</sup> at the cost of decreased execution speed. The routine of dominant pass, subordinate pass, and threshold reduction continues until the bit budget is exhausted or until some distortion criterion is reached; at that point, the encoder transmits a stop symbol and begins processing the next frame in the video sequence.

The image decoder simply inverts each operation performed by the encoder in reverse order: that is, it arithmetically decodes the bit stream to create symbols, and then it decodes the symbols to progressively refine its estimates of the wavelet coefficients. This process is illustrated by the block diagram shown in Fig. 5b. Because the arithmetic coding model is backward adaptive, we need not transmit it as side information. Furthermore, because the decoder's knowledge exactly mirrors that of the encoder at any given point in the processing of the bit stream, there is no need to transmit pass delimiters or synchronization signals (although these might be useful for resolution-scalable compression). Also, the resolution enhancement bits transmitted during the subordinate pass do not need any location specifiers; the decoder knows the exact transmission order of these bits because it has reconstructed the same subordinate list as the encoder had at that point in the processing.

## IV. Feature-Based Compression

### A. Feature-Selective Resolution Control

The conventional EZW algorithm allocates resolution uniformly across the image. To achieve this spatial uniformity, it actually distributes resolution to the wavelet coefficients nonuniformly across the wavelet scales, that is, frequency subbands. Specifically, a coarser scale is allocated twice as much resolution as the next finer scale; this allocation is implicitly controlled by the use of a unitary or unitarylike scaling in the wavelet decomposition. Such coefficient scaling has the effect of increasing the gain in each successive level of the two-dimensional wavelet decomposition by a factor of 2. To understand how a multiplicative factor implicitly controls resolution, consider the following example: Assume that the true value of a



wavelet coefficient is 85 and that the final dominant pass through the coefficients ends with threshold  $T = 64$ . Without rescaling, the final uncertainty interval for this coefficient in the decoder will be  $[64, 128]$ , resulting in a reconstructed coefficient value of  $96 \pm 32$ . Now, assume instead that this coefficient is multiplied by 2 prior to coding; that is, we code the value 170. During the pass when  $T = 128$ , the coefficient will be declared significant and approximated in the decoder by  $192 \pm 64$ . After the refinement pass, however, the new approximation will be  $160 \pm 32$ . Because, the encoder stops after the dominant pass for  $T = 64$ , the coefficient will receive no further refinement bits. Dividing the coefficient approximation by 2 restores its original scaling and results in the final estimate of  $80 \pm 16$ . Thus, the uncertainty region of the new estimate,  $[64, 96]$ , is one-half that of the original.

Whereas scaling is used in the classical EZW algorithm to implicitly control the bit allocations to coefficients in the different wavelet scales, it can also be used explicitly to weight features in the imagery. By our definition, a feature is anything in the imagery that can be localized in space and/or frequency. For example, a tank in a reconnaissance photo might be a spatial feature to which we want to allocate additional resolution. On the other hand, an orchard in the same photo could represent a space-frequency feature, that is, a feature that is defined by a frequency spectrum within a spatial region, whose resolution allocation should be reduced to increase the resolution of other more interesting portions of the image. Either way, the allocation of resolution (and thus bits) is most easily controlled by scaling coefficients up or down by the appropriate powers of 2 prior to encoding. Note, however, that rescaling only adjusts the resolution of coefficients relative to other coefficients: This process is a zero sum game. Thus, scaling all of the wavelet coefficients up by a factor of 2 will have no effect on the resolution of the reconstructed image.

## B. Coding Scheme

By using coefficient rescaling, we create a single embedded bit stream in which different wavelet coefficients are represented with varying precision. If all of the coefficients corresponding to a single zerotree are coded at a specified precision, then the corresponding region of the reconstructed image will be reconstructed at the same precision (assuming that orthonormal wavelets are used). The "x"s in Fig. 6 correspond to the coefficients that form a complete zerotree, and it is these coefficients that must be multiplied by a power of 2 scaling factor to increase the resolution of the corresponding  $16 \times 16$  image region. The size of the region in the image that corresponds to 1 zerotree (the minimally controllable region) for a depth  $L$  wavelet decomposition is  $2^L \times 2^L$ . Thus, to spatially vary the resolution across the image, one need only vary the coefficient scaling

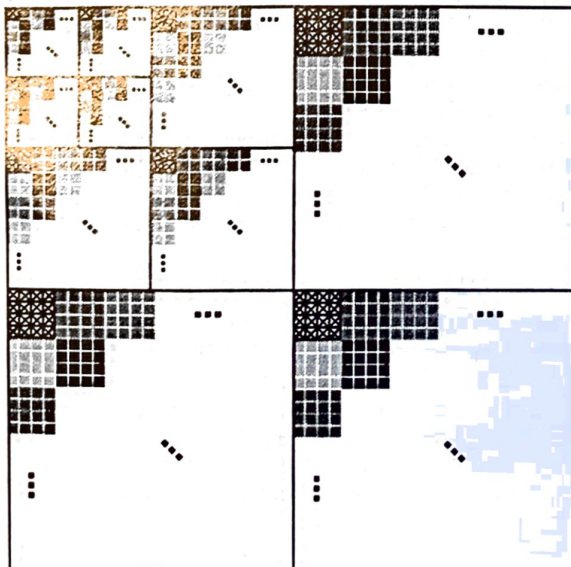


Fig. 6 All coefficients shaded in gray are rescaled together.

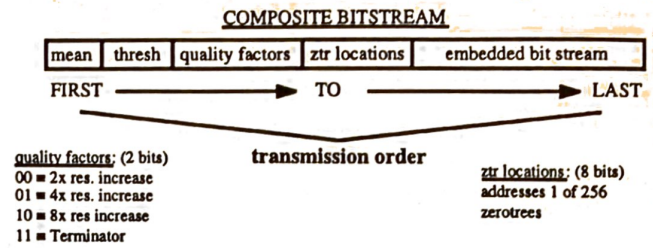


Fig. 7 Organization of compressed bit stream.

on a zerotree by zerotree basis. If, on the other hand, one wishes to increase or decrease the resolution of specific frequency bands within a given region, one must vary the scaling factor between wavelet scales corresponding to the same zerotree. Note that by using a fixed wavelet decomposition, we have limited the amount of frequency control that can be achieved, that is, the bandwidth of each image subband increases by a factor of 2 in each dimension as the wavelet scale decreases. If instead one used an adaptive wavelet packet decomposition,<sup>12,13</sup> one could also optimize the bandwidth of the subbands for the space-frequency features of interest. Because such wavelet packets greatly increase the complexity of the encoder, however, we have chosen not to use them in our system.

For the decoder to correctly reconstruct the wavelet coefficients, it must know which areas have been rescaled and by what scaling factor. The only exception to this general rule is when a coefficient has been scaled down so much that it will be reconstructed as 0 by the decoder. In the case where small areas of enhanced resolution are desired, the side information describing the rescaling to the decoder is very compact and does not require lossless compression. Figure 7 shows the organization of the compressed bit stream. First, the image mean (which was subtracted from the image prior to the wavelet decomposition) and starting threshold are sent; this is always done for any embedded compression algorithm. Second, a set of quality factors are transmitted, one for each zerotree whose resolution has been increased. In the current instantiation, each quality factor is a 2-bit quantity and allows for three levels of resolution increase ( $\times 2$ ,  $\times 4$ , and  $\times 8$ ). Because the number of zerotrees with resolution increases is not predetermined, a fourth parsing symbol is also allowed which terminates the quality factors section and tells the decoder how many ZTR locations to expect. Each ZTR location is a numeric value that uniquely indexes one zerotree; if the image is of size  $512 \times 512$  and a depth 5 decomposition is used, then 1 B is sufficient to uniquely identify a zerotree. One zerotree location is transmitted for each quality factor, and the ordering is such that each zerotree location index corresponds exactly to a previously transmitted quality factor. In addition, no parsing symbol is needed because the decoder already knows how many zerotree location indices to expect. Finally, the embedded bit stream containing the compressed representation of the actual image is transmitted to the decoder.

One might note that the proposed method of transmitting the side information will not be particularly efficient if a large number of zerotrees are rescaled. In such a situation, it might be more efficient to simply send 1 bit for each zerotree indicating whether or not its scaling has been altered along with an ordered list containing the magnitudes of the rescaling. In the case where there are 256 total zerotrees, transmitting the ZTR location specifiers in this way would require exactly 32 B. Thus, the tradeoff is clear: If fewer than 32 zerotrees are rescaled, an explicit index to each should be transmitted; otherwise, the 1-bit/zerotree rescaling map should be sent.

## V. Results

For the results presented in this section, we use a five-level decomposition based on a 5/3 biorthogonal wavelet transform [called (2, 2) in Ref. 14]. To increase its speed, we use lifting to implement this wavelet, which allows the high- and low-pass filters to share computations.<sup>15</sup> In addition, lifted transforms are in place and, thus, do not require large amounts of scratch memory during computation. Because a five-level decomposition has been selected, the



minimally controllable spatial region is  $32 \times 32$  (not taking into account the overlapping basis functions of the transform). From a sequence of 800 frames, a training set of 10 images containing the group of 4 buildings indicated by the white arrow in Fig. 8a was selected. Note that in Fig. 8a squares have been added to highlight enhanced regions and that the arrow indicates the particular region of interest for which the system was trained.

From this training set, a MACH filter was constructed to recognize the buildings as the feature of interest. The size of the filter in this case was  $64 \times 64$ , which is larger than the minimally controllable region as determined by the depth of the wavelet transform. The regions with the top three correlation peaks, that is, the best three matches, are allocated resolution according to the following formula: region 1 always receives eight times the resolution of the background; regions 2 and 3 receive the same if their correlation peaks are within 5% of region 1, but they receive four times the resolution if the peaks are within 20%, and twice the resolution if less than 20%. The reasoning behind such an allocation scheme is that, although the MACH filter ideally will always return the highest correlation peaks for the true target, this is not always the case. If a false alarm has the highest peak value, presumably the true target has a similar value and, hence, correlation peaks within 5% of the top peak receive the same resolution. If the correlation scores are significantly different, the probability that the lower scores are



Fig. 8a Reconstruction of image compressed by 80:1 ratio.

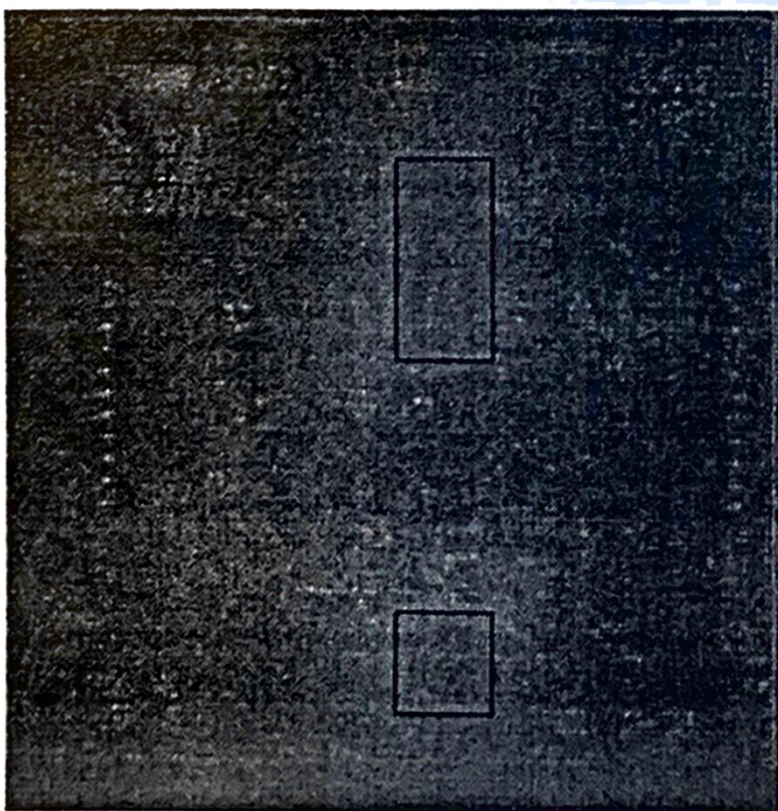


Fig. 8b Error residual between reconstructed and original image where white areas in residual denote large errors.

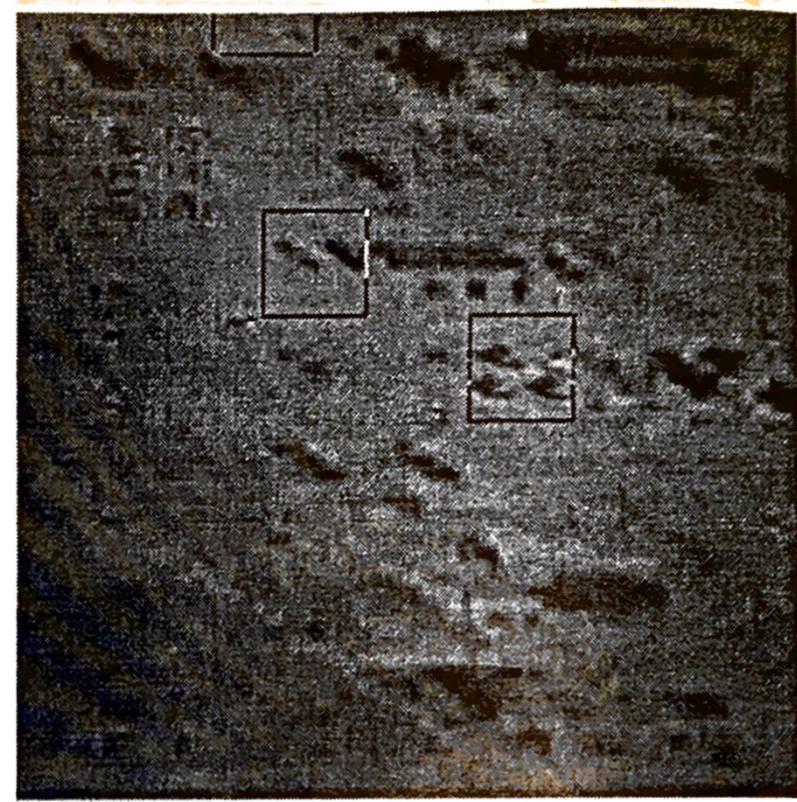


Fig. 9a Reconstruction of image compressed by 160:1 ratio.

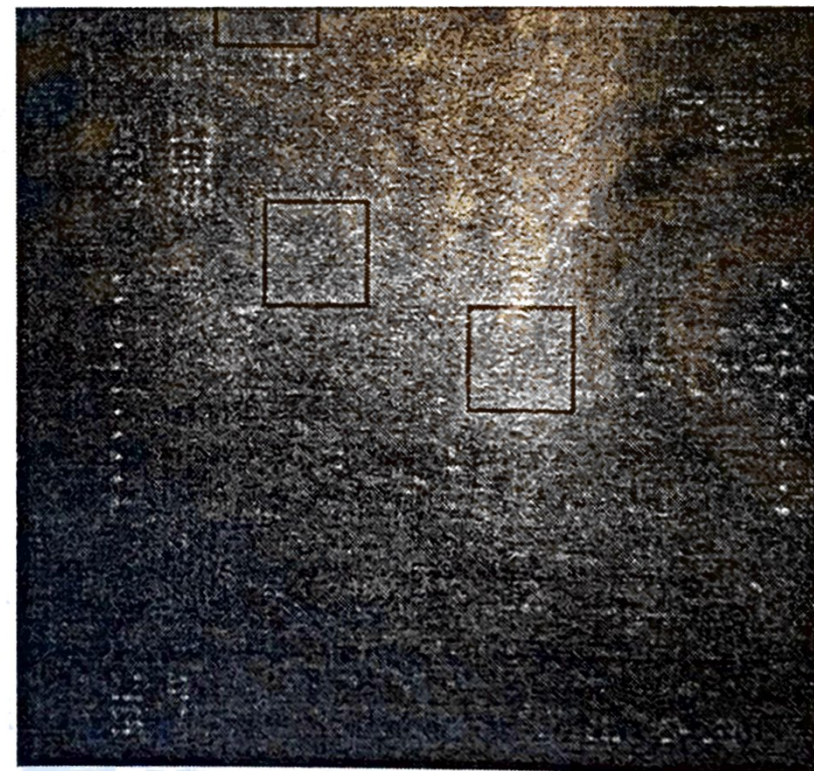


Fig. 9b Error residual between reconstructed and original image

true targets decreases and the region receives a lower bit allocation. Figures 8 and 9 show the results for compression at ratios of 80:1 and 160:1, respectively. Again, squares have been added to highlight enhanced regions. By looking at the error residuals (Figs. 8b and 9b), one can see the differences in the allocation of resolution to the different regions. In both examples, the area containing the group of four buildings has the highest resolution whereas the other two highlighted regions have lower resolution (but still higher than the background). As already mentioned, the choice of three high quality regions is somewhat arbitrary but it does depend somewhat on the design of the MACH filter. A tradeoff between the amount of compression and the probability of detection and false alarms needs to be considered when actually implementing this algorithm in practice.

## VI. Discussion and Conclusions

We have described a synthesis of two disparate areas of image processing: compression and ATR/ATC. The regional compression algorithm expands the effective bandwidth available by maximizing the information content of the transmitted imagery, using information from the ATR algorithm. One obvious area where this technique may prove valuable is in the UAV/UCAV arena. For example, the use of the ATR/ATC driven compression, analysis by a human operator is simplified by allowing rapid identification of potential areas of interest. A second area where this work could be extended is image database management. By utilizing regional compression driven by an ATR/ATC algorithm it is possible to achieve us



compression ratios ( $>80:1$ ) while preserving image quality in areas that may be of interest. The potential savings in communications bandwidth could enable more vehicles to operate simultaneously than would be possible with standard compression techniques currently in use.

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